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Handbook of Reading

How is Information Integrated across Fixations in Reading?

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How is information integrated across fixations in reading?

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Abstract

This chapter explores the integration of information acquired over multiple eye fixations during reading by reviewing studies using the boundary paradigm (Rayner, 1975). This integration process is examined for information extracted from (a) the end of the fixated word, (b) the word to the right of the fixated word, and (c) the word two words to the right of the fixated word. The studies reviewed show that the amount of information integrated across eye fixations varies for these three different types of previewed visual information.

Furthermore, it is seen that a large variety of information extracted from a parafoveal word is integrated across fixations, including orthography, phonology, and semantics. We consider how such integration processes operate across several different languages to allow us to understand how the visual form of text, along with how linguistic characteristics are coded in a language, constrain such processing. We conclude that readers preferentially integrate the information that is most useful for the initiation of lexical access.

Keywords: Preview benefit, parafoveal processing, eye movements, reading, orthography, phonology, semantics, morphology, cross-linguistic differences.

During reading, saccadic eye movements are made in order to fixate a word in high acuity foveal vision, so that it is processed as efficiently as possible. The fovea is a small region of 2° of visual angle, which, depending on factors such as font size and viewing distance, will typically extend over approximately six characters during reading. Beyond the fovea visual acuity is considerably reduced, in the parafovea. The parafovea extends a further 4° of visual angle to either side of the fovea (Balota & Rayner, 1991). *Saccades* are rapid ballistic eye movements which move the eye from one point to another, and *fixations* are the periods of stillness between them. It is during the fixations that visual information is extracted from the page, and a large body of research has shown that the amount of time a word is fixated is tightly linked to the processing of that word (see Schotter and Rayner, this volume). While a large proportion of the processing of a word takes place in foveal vision, it is not the case that encoding only begins upon direct fixation of the word. Rather, a word is often partially processed on a fixation on a prior word. The parafoveal information extracted from this fixation is then carried over and integrated with foveal information that is available when the word is fixated. Furthermore, a single word is sometimes fixated more than once, in which case the information extracted during these multiple direct fixations must also be integrated. The process of integrating information extracted across multiple fixations is the focus of the current chapter.

The fact that a word is often processed over multiple fixations is apparent from studies using the moving window paradigm (McConkie & Rayner, 1975). In this paradigm, a window of normal text is set by the experimenter around the point of fixation. Within this window the characteristics of the text being read are preserved, whereas outside the window the text is masked. As a saccade is made a display change occurs, so that a new window of unmasked text is set around the new point of fixation (see Figure 1). This display change typically completes prior to the end of the saccade, and as such, participants are usually

unaware of the manipulation, due to visual information not being encoded during a saccade (e.g., see Martin, 1974). The smallest window size for which reading occurs at a rate similar to normal reading is referred to as the perceptual span. As such, this paradigm gives an estimate of how much information readers extract during a single fixation, albeit with no indication about the form of the extracted information. For English, this extends 3-4 character spaces to the left and 14-15 characters to the right of fixation (McConkie & Rayner, 1975; McConkie & Rayner, 1976). While readers are able to extract information 14-15 characters into the parafovea, the average saccade tends to move the eyes 7-9 characters forward (Rayner, 1998). Therefore, readers usually have overlapping perceptual spans across two fixations, meaning that the same word is often available for processing across multiple fixations. It is clear from this that readers are often integrating information across fixations, since their reading speed decreases when the window is smaller than the size of the perceptual span and a word is thus not available for processing across multiple fixations.

While the moving-window paradigm can be used to demonstrate that information is processed across multiple fixations, it does not allow us to infer the nature of this processing, or the type of representation which is integrated across fixations. Several theoretical possibilities exist as to why restricting parafoveal information in moving window studies slows down reading. For example, one early theory proposed that purely visual information obtained from the parafovea is stored between fixations, and that new visual information obtained upon direct fixation is added to this visual representation (McConkie & Rayner, 1976b). Pollatsek, Lesch, Morris and Rayner (1992) proposed an approach based around the idea that phonological coding serves an important role in silent reading, by helping to create a representation of identified words in short term memory. According to this approach a phonological code is obtained for a word seen in the parafovea, which is used to preserve the memory of that word across fixations. A third possibility is that a parafoveal stimulus

activates a set of lexical entries on the basis of several abstract word characteristics (e.g. orthography, phonology, morphology, and semantics), and that this activation is carried across multiple fixations. This lexical activation may then lead to the faster identification of a word once it is directly fixated, thus explaining the slowdown in reading when parafoveal information is denied in the moving window paradigm.

In order to discriminate between the possibilities outlined above it is necessary to manipulate specific characteristics of a single word in the parafovea and examine how this affects fixation times on that word. This has been investigated using a second eye contingent change technique, the boundary paradigm (Rayner, 1975). In the boundary paradigm an invisible boundary is set (usually) at the end of a pre-target word (see Figure 2). Prior to the eyes crossing the boundary, a preview string is presented instead of the target word. This preview can be the target word itself (an identity preview), a different word, or a nonword. The preview quickly changes to the target word as a saccade is made that crosses the boundary. As will be seen, this technique has been widely used and has demonstrated that when readers are given an identity preview of a target word, they take less time to process and identify it relative to when they are given an incorrect preview. This advantage is referred to as the *preview benefit*. The fact that readers gain a preview benefit strongly suggests that they have extracted and processed information about the preview string before fixating it, and then integrated this information with information obtained on the next fixation, usually made on the word itself. By varying the relationship between the preview and the target, it is possible to discover the types of information that are extracted and integrated across fixations, and to discriminate among different explanations regarding the nature of trans-saccadic integration. For example, if preview benefit effects were purely driven by visual overlap between a preview and target word, it would suggest that the integration process is dependent upon the combination of visual information into a single percept. Were it simply the case that

a phonological code is used to aid short term memory of a parafoveal stimulus then preview benefits should only be observed for previews that share phonological information with the target word. If, however, it was to be found that preview benefits are determined by a wide range of abstract information about a parafoveal word, including orthography, phonology, morphology, and semantics, it would suggest that the integration process works on the basis of lexical entries (representing multiple linguistic characteristics) that have been partially activated by the parafoveal stimulus. As will be seen throughout this chapter, a substantial amount of research supports this third position, with preview effects being documented for types of information that go beyond low-level visual similarity between the preview and target, or a phonological representation in short term memory.

In this chapter we will consider the integration of information from several different types of parafoveal stimuli. We will first examine how information is integrated across multiple fixations on the same word. We will then focus on the different types of information that are extracted and integrated from the word to the right of fixation, demonstrating the range of different types of information that are integrated across fixations. We will also explore whether information is integrated from two words to the right of fixation. Finally, we will briefly discuss factors that modulate the degree to which information is integrated across fixations. We will restrict our discussion to research conducted on adult readers whose reading has developed typically. While the majority of our discussion will focus on studies conducted in English and other similar spaced alphabetic languages, we will also briefly discuss studies conducted in languages in which the phonological, morphological, or semantic characteristics associated with a word are orthographically coded in a manner different from English. These studies will be considered with regard to how these cross-linguistic differences affect integration across fixations.

Before proceeding further it is necessary to briefly discuss some different eye movement measures that have been widely used to assess preview benefit. There are several fixation time measures that can be calculated, which vary regarding the extent to which they take one or multiple fixations on a word into account. Early measures include *first fixation duration* (the mean duration of the initial fixation on a word) and *gaze duration* (the amount of time between first fixating a word, and making a saccade away from it). Later measures take further re-fixations on a word into account. For example, *total viewing time* includes all fixations made on a word (including later fixations made when a word is re-read).

THE INTEGRATION OF INFORMATION DURING REFIXATIONS

Not all saccades move the eyes onto a new word. Rather, a reader will refixate approximately 15% of words (Rayner, 1998). Refixations are more likely for longer words, and the most common pattern is for the initial fixation to be made towards the beginning of a word and the second towards the end (Rayner, Sereno, & Raney, 1996). The fact that refixations often follow this pattern suggests they are made partly due to a need to process characters from the end of a word more centrally within foveal vision. As such, it is worth considering the extent to which information from the end of a long word is integrated with that from the beginning of the same word across fixations. Drieghe, Pollatsek, Juhasz, and Rayner (2010) examined this for monomorphemic words (e.g. *fountain*) and unspaced compounds, which are made of two smaller lexemes (e.g. *bathroom*). A variation of the boundary paradigm which was first implemented by Hyönä, Bertram, and Pollatsek (2004) was used, in which the boundary was placed in the middle of the word instead of between words. In Drieghe et al.'s study, the boundary was between the first and second constituent in the unspaced compounds, or between the corresponding letters of a monomorphemic word that was matched on length, overall frequency, and initial bigram and trigram frequency. In the incorrect preview conditions, the final letters of the target word after the boundary were

replaced (e.g., *fountaom*, *bathroan*). There was a large effect of this preview manipulation, with readers having gaze durations of 151 ms and 146 ms longer in the incorrect preview conditions than in the identity conditions as assessed by the gaze duration on the post boundary portion of the target word for the monomorphemic words and the unspaced compounds, respectively. This demonstrates that when a word is fixated twice, the information from the end of the word has already been processed to a considerable degree during the initial fixation on the word, and this information is integrated with information gained upon refixation.

Although preview benefits from the second portion of the target words were similar for the monomorphemic and unspaced compound words, there were differences in the degree to which the preview affected fixations prior to crossing the boundary. That is, fixations on the first half of a monomorphemic word were lengthened by the incorrect information in the second half of the preview; however, this was not the case for the unspaced compound words. The characteristics of a parafoveal letter string affecting fixation durations on the prior, foveal, text is referred to as a parafoveal-on-foveal effect (for a review see Drieghe, 2011). These parafoveal-on-foveal effects are generally viewed as evidence that information in the parafovea is being processed in parallel with information in the fovea. Otherwise this parafoveal information would be processed too late to affect the fixation duration on the foveal word. The fact that these preview effects were observed for monomorphemic words but not for unspaced compounds indicates that while the former are processed as single units, the latter are processed, at least to some degree, as two independent sub-units, and this in turn affects the rate at which parafoveal information is integrated.

Häikiö, Bertram, and Hyönä (2010) also investigated the integration of information from the second lexeme of an unspaced compound word (in Finnish, all compound words are unspaced), using the within-word version of the boundary paradigm. They varied whether

readers received a correct preview of the second constituent or a preview in which all but the initial two letters were replaced. There was a main effect of the preview manipulation on fixation time on the second constituent, and an interaction between the frequency of the compounds and the preview manipulation during fixations prior to crossing the boundary (i.e. for the high frequency compounds, an incorrect preview resulted in longer fixations on the first constituent before the boundary was crossed whereas this was not the case for the low-frequency compounds). Häikiö et al. proposed that the high-frequency compounds were identified via a single lexical entry, whereas the low-frequency compounds were identified as two separate lexemes; thus the incorrect preview was only processed in parallel with the first constituent in the high-frequency compounds.

Hyönä, Bertram, and Pollatsek (2004) demonstrated that the frequency of an unspaced compound's first constituent also affects the integration of information from the second constituent across fixations. They manipulated the frequency of the first constituent of the compound word and all but the two initial letters of the second constituent. These initial letters were either incorrect or correct until the saccade crossed from the first constituent to the second constituent. The preview benefit observed during fixations on the second constituent was larger when the first constituent was a low frequency word than when it was a high frequency word. However, there was no evidence of an effect of the letters of the second constituent being incorrect during fixations on the first constituent- even for the compounds with low frequency first constituents. This suggests that the difference in the preview effect on the second constituent was not caused by the second constituent being processed as part of the whole compound. Rather, Hyönä et al. proposed that these effects were driven by the fact that the low-frequency first constituents potentially combined with fewer second constituents to form a compound word than the high-frequency first constituents. As such, the set of potential second constituents was more constrained given a

low-frequency first constituent, and thus was processed more efficiently in the parafovea, as a separate lexeme (See Cui, Yan, Bai, Hyönä, Wang & Liversedge, 2013 for a similar argument in processing Chinese compound words). Taken together, Hyönä et al., Drieghe et al. (2010), and Häikiö et al.'s (2010) findings suggest that a number of factors influence the amount of information that is integrated from the second constituent of an unspaced compound across fixations, and the time course of this processing. How highly constrained the second constituent is influences the amount of information that is integrated across fixations. Furthermore, the frequency of the whole compound influences the time course of when this information first has an observable effect on processing. Further research is required in order to extend current understanding of the factors that determine how the second constituents of unspaced compound words are processed in the parafovea.

White, Bertram, and Hyönä (2008) undertook an experiment in Finnish that investigated whether semantic information from an unspaced compound's second constituent is integrated across fixations. In this study, participants were given a preview of the second constituent of an unspaced compound (*vaniljakastike* 'vanilla sauce') while fixated on the first constituent. There were four possible previews: an identity preview (*vaniljakastike* 'vanilla sauce'), a semantically related preview (*vaniljasinappi* 'vanilla mustard'), a semantically unrelated preview (*vaniljarovasti* 'vanilla priest'), and a pronounceable nonword preview (*vaniljaseoklii*). The identity preview led to shorter fixations on both the second constituent and across the whole compound than any of the other preview types. While the semantically related preview provided no benefit relative to the unrelated and nonword previews in either first fixation duration or gaze duration, on either the second constituent or whole compound, there was a benefit in *regression path durations* within the compound (this includes all fixations within the compound from first fixating the second constituent, until a rightwards saccade was made out of the compound). This fairly late effect

of the semantic preview suggests that semantic information was extracted from the second constituent of the compound, but was not integrated immediately upon fixating the target constituent. Rather, integration only occurred during the later phases of compound word processing.

In summary, when a word is fixated multiple times, information is indeed integrated across these fixations. This is true for both monomorphemic and compound words, with substantial preview effects being found within both types of word (Drieghe et al., 2010). The extent to which this information is integrated across fixations within a compound word depends on both the frequency of the whole compound word (Häikiö et al., 2010) and the extent to which the first constituent constrains the second (Hyönä et al., 2004).

THE INTEGRATION OF INFORMATION FROM WORD $N+1$.

Orthographic codes

A basic question that we can ask in relation to the integration of information across fixations is whether the information that is integrated is based entirely on the visual form of the words or is based on abstract linguistic information that is derived from the orthography of the words. Studies have addressed this by examining the effects of changing the visual characteristics of text across saccades while holding letter information constant. McConkie and Zola (1979) had participants read text in which words were written in alternating case, with the case of each letter changing during saccades (e.g. *ReD* -> *rEd*). This manipulation changed the visual information between fixations, while keeping the letter identities constant. There was no slowdown in reading when the case changed across fixations relative to a condition with no display changes, indicating that the integration of information is not restricted to visual forms. Similarly, Rayner, McConkie, and Zola (1980) showed that participants were no slower at naming a target word when case changed across fixations as opposed to staying the same.

While changing the case of the letters across fixations does not have a significant effect on reading, other work has demonstrated an effect of the visual similarity between a preview and target word. In a meta-analysis of studies in English using the boundary paradigm, Hyönä, Bertram, and Pollatsek (2004) showed that using visually similar replacement letters (e.g., *b* and *d*) results in smaller preview effects relative to an identity condition (15 ms in gaze duration, on average) than using visually dissimilar letters (e.g. *p* and *s*; 41 ms effect on average). These findings suggest that the orthographic information that is integrated across fixations is in the form of abstract letter identities, which have been activated by low-level visual features. Since visually similar letters will co-activate each other due to shared features (e.g. the vertical ascender in *d* will activate *d*, *b*, and *h*), previews with similar letters will activate the target to a greater extent than previews without similar letters. This also explains why case changes across fixations do not affect reading. While low-level features changed across fixations in these studies, letter identities did not. Thus, a (case-independent) letter representation would have been activated by the features of its lower-case form on one fixation and the features of its upper-case form on the next (and vice versa). As long as letter activation was carried across fixations, it would not have mattered whether this activation was due to the same low-level features on all fixations, or different features on each fixation.

There is evidence that letters from different positions within a word are not equally important when information is integrated across fixations. Inhoff (1989a) gave previews of 6-letter words in which the whole word (e.g. *survey*), the initial trigram (e.g. *surxxx*), the final trigram (e.g. *xxxvey*) or nothing (e.g. *xxxxxx*) was available. Furthermore, the reading direction was varied (e.g., *a recent survey* vs. *survey recent a*), with participants reading from right to left in the latter condition, in order to ensure that any letter position effects were not due to visual acuity. The initial trigram led to slightly, though not significantly, greater

facilitation than the final trigram (16 ms vs. 12 ms in first fixation duration) regardless of reading direction. Furthermore, when visually dissimilar replacement letters were used instead of *xs* Inhoff found that the final trigram alone no longer provided a significant preview benefit, whereas parafoveal availability of the initial trigram still led to a significant benefit of 6 ms. Briehl and Inhoff (1995) further investigated this issue by varying the number of correctly previewed letters and their position in a word, and found that previewing external and initial letters was significantly more facilitative than previewing internal letters. One probable reason for the greater benefit of external letters is reduced crowding relative to internal letters, due to being located next to a space. Briehl and Inhoff also found that previews of both final and initial letters together did not facilitate processing significantly more than previews including only initial letters, suggesting that final letters do not play a particularly important role in trans-saccadic integration. However, in both studies, whole word previews were more facilitative than would have been expected had the effect of each extra letter been additive. This suggests that the letters were parafoveally encoded as part of a whole word, and mutually reinforced each other's activation.

While word-initial information in English is given preferential treatment in trans-saccadic integration, this does not generalize to Chinese. Rather than consisting of a string of letters representing a phonological code, Chinese characters are made up of a number of strokes which form sub-units known as radicals. Many characters consist of more than one radical, and the majority of these characters contain a radical that carries phonological information and another that carries semantic information. While these radicals contain this abstract information, the relationship between a character and its radicals is not always strong, with, for example, the pronunciation of only 30% of phonetic radicals corresponding to that of the full character (Zhou & Marslen-Wilson, 1999). As such, two characters with the same phonetic radical may be pronounced differently. Clearly linguistic information is

orthographically coded in Chinese in a vastly different way than in English, and so may be integrated differently across fixations. Liu, Inhoff, Ye, and Wu (2002) conducted a boundary study in which the preview and target shared orthographic information via a) the semantic radical, b) the phonetic radical, c) stroke information while sharing neither radical, or d) shared no orthographic information. Liu et al. found that participants gained a significant preview benefit given an overlapping phonetic radical, but not from the other conditions. This effect was observed regardless of whether the target and preview character were phonologically similar. The phonetic radical typically appears on the right side of a Chinese character. Thus orthographic preview benefit is driven by character-final information in Chinese and word-initial information in English. One possible reason for this is that parafoveal orthographic information is used to initiate lexical access, and that the optimal information for this differs across languages. In English the initial letters of a word may be more useful, in part due to their importance in generating a phonological code. However, Liu et al. argued that in Chinese the phonetic radical is more useful for two reasons. First, they claimed that it is the smallest orthographic unit that is always represented in the character lexicon, with it forming a character in isolation. They also claimed that the phonetic radical provides more discriminative information with which to select character candidates from the lexicon. Thus, while different orthographic information is integrated to differing extents in each language, the time course of processing appears to be driven by the underlying principle of what information is most optimally used to initiate lexical access.

As well as investigating how letter identity information is integrated across saccades, researchers have also examined letter position encoding in the parafovea (see Perea, this volume, for a general discussion of letter position coding). Johnson, Perea, and Rayner (2007) provided readers with parafoveal previews in which two letters had been transposed (e.g. *loewr* as a preview of *lower*) or substituted (e.g. *loanr*), finding that the transposed letter

previews were more facilitative than the substituted letter previews. Johnson (2007) found that this effect endured even when the transposition was made between non-adjacent letters (e.g. *flower* to *flewor*). Johnson and Dunne (2012) presented participants with previews that varied in whether letters were transposed or substituted, and whether they created a nonword or a word which was orthographically similar to the target (e.g., *besat*, and *beats* as transposed letter previews and *berut*, and *beach* as substituted letter previews for the target word *beast*). Preview effects were driven exclusively by the extent of orthographic overlap between the previews and the targets, such that the two transposed letter previews resulted in shorter fixations on the target word than the two substituted letter previews. There was no significant difference between whether the preview was a word or non-word. This study provided further evidence for the transposed letter effect during reading. Furthermore, these findings suggested that processing in the parafovea does not typically proceed to the later stages of lexical processing, during which lexical candidates compete by inhibiting the activation of orthographically similar words. If this had occurred, the word previews should have led to smaller preview benefits than the nonword previews. Together, these studies show that the identity of a letter maintains activation across fixations independent of position. However, this is not to say that letter position *per se* is not important. Clearly it is, since the identity preview always provided reliably more benefit than the transposed letter previews in all of these studies.

The studies we have discussed in this section demonstrate that information about both letter identity and letter position is integrated across fixations. The importance of letter identity information is weighted in relation to a letter's position within a word, and this factor has a differential influence across orthographies (see Frost, this volume, for an in-depth discussion regarding how orthographic encoding may differ across orthographies).

Phonological codes

One reason for the greater importance of word initial letters in preview benefit may be their role in generating a phonological code to initiate lexical access. Accordingly, it might be expected that an element of such a code might also be taken from the parafovea and integrated with the phonological codes extracted when the word is fixated. In the following section, we consider a series of studies that examined whether phonological codes are integrated across fixations and the nature of these representations (see Pollatsek, this volume, for a more in-depth discussion of phonological coding during reading).

One way in which phonological processing has been investigated is through the use of homophones in preview studies. Homophones are two words that are spelled differently but pronounced the same. Pollatsek, Lesch, Morris, and Rayner (1992) used the boundary paradigm and presented participants with homophone previews (e.g. *beach* as a preview for *beech*) or orthographic control previews (e.g. *bench*). Participants gained a greater preview benefit from the homophones than the controls. Thus, these results suggest that the overlapping phonological code was integrated across fixations. Chace, Rayner, and Well (2005) replicated this effect, but only in skilled university aged readers, with less skilled university aged readers showing no preview effects. Bélanger, Mayberry, and Rayner (2013) extended the finding by manipulating the relative frequency of the homophone preview and target (i.e., the higher frequency word of the homophone pairs was the preview in half the trials and the target in the other half). Participants gained a phonological preview benefit from the high frequency preview but not from the low frequency preview.

While the above studies demonstrate that readers integrate phonological codes across fixations, it is unclear whether this is driven by addressed or assembled phonology. That is to say, the reader may either gain access to the phonological code via the identification of a complete orthographic representation (a lookup process) or through the use of grapheme-phoneme correspondence rules to assemble a phonological code. Miellet and Sparrow (2004)

investigated this in French by giving participants nonword homophone previews (e.g. *maizon* as a preview for *maison*) or orthographic controls (e.g. *mailon*). Despite the homophone preview being a nonword, it facilitated reading. The fact that this effect occurred when the preview strings were nonwords suggests that the benefit comes from assembled phonology, since there is no stored lexical representation via which a phonological code might be accessed (for evidence of English readers gaining a phonological preview benefit from nonwords see Ashby, Treiman, Kessler, & Rayner, 2006). However, the fact that Bélanger et al. (2013) observed an influence of word frequency on phonological preview effects suggests that readers do sometimes retrieve, as opposed to assemble, a phonological code, with it being possible to extract this information more rapidly from a high-frequency word than from a low-frequency word. Thus, depending on the circumstances, readers may make use of either addressed or assembled phonology. Further research is needed to determine the factors affecting which route a reader takes to obtain the phonological code of a parafoveal word.

The studies discussed in this section up to this point all manipulated phonological overlap at a whole word level. Other studies have examined the integration of more fine-grained phonological information within a word. Ashby and Rayner (2004) examined the role of syllabic structure by giving participants previews of words with either a consonant-vowel-consonant (e.g. *concave*) or consonant-vowel (e.g. *device*) initial syllable. A space manipulation was also used so that previews either preserved (e.g. *de_pxw* for *device*) or violated (e.g. *dev_px*) this structure. Participants remained fixated on the target word for less time when the preview maintained the structure. This was true even for the words with a CV initial syllable, despite the incongruent preview providing more orthographic information. Thus, phonological information at the level of syllables is integrated across fixations, and having these syllables clearly visually delimited in the parafovea may facilitate subsequent processing to a greater extent than a larger number of letters which do not maintain syllabic

structure. This suggests that word initial letters may be more facilitative partly because of their role in generating a phonological code. Fitzsimmons and Drieghe (2011) demonstrated that the extraction of a word's syllabic structure in the parafovea must occur rapidly. In this study either a monosyllabic or a disyllabic word matched on word length, frequency, predictability, number of orthographic neighbors and mean bigram frequency was embedded into a sentence. The monosyllabic word was skipped more regularly than the disyllabic word. On the assumption that the parafoveal word's syllabic structure influenced where the next saccade was targeted, this indicates that this information was extracted early enough during parafoveal processing for it to influence saccadic targeting.

Ashby et al. (2006) investigated whether vowel information is integrated across fixations by contrasting vowel concordant and vowel-discordant previews (e.g. *cherg* and *chorg*, respectively, as previews for *chirp*). Vowel concordant previews were more facilitative, even when the vowel's pronunciation needed to be modified by subsequent consonants to be concordant (e.g. *raff* as opposed to *rall* as a preview for *rack*). Thus, this study demonstrated that individual vowel sounds are also integrated across fixations.

The nature of alphabetic languages means that there is a relatively direct link between orthography and phonology in that letters link reasonably reliably to certain phonemes. This is not true for a character based language, such as Chinese. In Chinese, similar-looking characters often have different pronunciations, and homophonic characters may be entirely visually distinct (Hoosain, 1991). Furthermore, as mentioned above, Chinese characters contain a phonetic radical, which in some cases represents the character's phonology, but in other cases contains phonological information which does not match the character's pronunciation. Tsai, Lee, Tzeng, Hung, and Yen (2004) investigated whether Chinese readers integrate phonological information across fixations despite the deeper orthography, and whether the relationship between the phonetic radical and whole character influences this

process. Participants were presented with homophonic previews and orthographic control previews. Half of the target characters were pronounced in the same way as other characters sharing the same phonetic radical (i.e. high consistency) and the other half were not (i.e. low consistency). For high consistency targets a phonological preview benefit was observed in both first fixation and gaze duration measures, whereas for low consistency targets the effect was only observed in gaze durations. Clearly, readers of Chinese integrate phonological information across fixations, and this information is extracted from both the whole character and the phonetic radical.

We have seen that phonological information is integrated across saccades both in English and in Chinese where there is a far less clear relationship between orthography and phonology. Furthermore, phonological information is extracted at both the whole word level, the character level, and from sub-units such as syllables and radicals. While we have discussed English as having a fairly direct link between orthography and phonology in comparison to a language such as Chinese, this relationship is less consistent in English than in many other alphabetic languages. As such, future work on parafoveal phonological processing should perhaps focus on these other alphabetic languages with more regular coding schemes more. It may be, for example, that in these languages (e.g., Spanish) even less skilled readers would show evidence of integrating phonological codes across fixations, unlike less skilled readers of English (Chace et al., 2005).

Morphological codes

A further form of information that may be integrated across fixations relates to a word's morphology. Often words can consist of more than one morpheme, and therefore, a word's constituent morphemes may be used to guide lexical access to the whole word form (e.g. *cowboy* may be identified via the lexical entries for *cow* and *boy*). Given this, readers may decompose a parafoveal word into its constituent morphemes, and integrate these units

across fixations. If this were the case, then a clearly defined parafoveal morphological unit could impact on subsequent fixations downstream in reading (Lima, 1987).

Several studies have examined this possibility in English (Inhoff, 1989b; Juhasz, White, Liversedge, & Rayner, 2008; Kambe, 2004; Lima, 1987). Researchers have taken the approach of using the boundary technique to provide parafoveal previews to either multimorphemic words (e.g. *revive*, *cowboy*) or monomorphemic control words (e.g. *rescue*, *carpet*) where the previews show a plausible morphemic unit (e.g. *reXXXX*, *carXXX*). The logic behind this manipulation was that a clearly delimited morphological sub-unit might allow participants to initiate lexical access of the word on this basis. For true multimorphemic words this should be facilitative, since the sub-unit would be represented as part of the target word's morphological structure. On the other hand, for the monomorphemic control words, there should be no advantage beyond an orthographic effect. The results of these studies generally suggest that morphology is not extracted in the parafovea, there being no difference between the preview effects for multimorphemic and control words. Both Lima (1987) and Kambe (2004) observed no effect for prefixed words (e.g. *revive*, *dislike*). Lima found no beneficial effects of providing just the prefix (e.g. *disxxxx* for *dislike*) of a multimorphemic word relative to a control word, and Kambe observed no effect of giving either the prefix or the stem (e.g. *xxxlike* for *dislike*). Thus, information about prefixes and affixes does not seem to play a role in trans-saccadic integration during English reading. Inhoff (1989b) found a similar pattern of results for words consisting of two morphemes that can stand alone as words (e.g. *cowboy*). Finally, Juhasz et al. (2008) removed a letter from both compound (e.g. *sawdust*) and monomorphemic (e.g. *lettuce*) words in a position that either preserved (e.g. *saw ust*, *let uce*) or violated (e.g. *sawd st*, *let ce*) a morpheme boundary. The preview that preserved the morpheme boundary did not result in faster processing than the preview that

violated this boundary, regardless of the type of word. This suggests that participants did not attempt to process the individual morphemes prior to direct fixation.

These studies provide little evidence that English words are decomposed into their constituent morphemes in the parafovea. Similarly, effects have not been observed in Finnish, a language in which spatially concatenated compounds are very common. Bertram and Hyönä (2007) gave participants previews of Finnish compounds that had a short (3-4 letters) or long (8-11 letters) first constituent, and were on average 12 letters long. The preview consisted of the whole compound or just the first three or four letters. This comprised all of the short first constituents, but not of the long first constituents. Were morphological sub-units being integrated across fixations, then a smaller difference between the two preview conditions for the compounds with short first constituents should have occurred, since participants should have gained a greater morphological benefit from the partial preview for the words with short first constituents. However, no interaction was observed between the preview type and first constituent length, suggesting that parafoveally available morphological information was not being used to initiate lexical access.

While morphological units may not be integrated across fixations in English and Finnish, morphological preview effects have been found in Hebrew (Deutsch, Frost, Pelleg, Pollatsek, & Rayner, 2003; Deutsch, Frost, Pollatsek, & Rayner, 2000; Deutsch, Frost, Pollatsek, & Rayner, 2005). In Hebrew, all verbs and most nouns and adjectives consist of two morphemes. One morpheme is the root, which represents the semantic nature of the word and consists of a series of three consonants. The other is the word pattern, which modifies the root by giving the word its class (i.e. noun, verb, adjective, etc.) and other characteristics. Of these two morphemes the root is more important to word meaning, and thus in Hebrew words there are three letters which provide more useful information than the rest of the letters. The two morphemes are interwoven, rather than concatenated. For example, the root morpheme

הבר and the word pattern מ____ת take the form of a word with interwoven constituents like תהברמ rather than a concatenated format like תמהבר. Word patterns' structures are highly constrained, such that they can only begin with certain consonants, and each letter imposes a set of transitional probabilities on subsequent letters. Consequently, it is possible for readers of Hebrew to rapidly determine which letters belong to the word pattern, and which belong to the root morpheme. In sum, within Hebrew words there are several letters which carry more useful semantic information than the others, and these letters are more easily located within and thus extracted from a word (see Frost, this volume, for a more in-depth discussion of the characteristics of Hebrew). Due to this, readers of Hebrew may be able to rapidly decompose a word into its constituent morphemes in the parafovea, and then integrate these morphemes across fixations.

Deutsch et al. (2000) first investigated whether the root morpheme is integrated across fixations in Hebrew using a naming paradigm. In this study, an isolated preview of a target word was presented in the parafovea. This preview was either the target word (e.g. תהברמ), the three letters of the root morpheme (e.g. הבר), an orthographic control (e.g. מבת), or an X-string. Participants gained a benefit from the morphological preview relative to the orthographic control, such that they named the target more quickly upon fixating it. Deutsch et al. (2003) extended this finding by showing that a morphological preview benefit is obtained during sentence reading using the boundary paradigm, and when the letters of the root morpheme had to be extracted from the letters of the word-pattern, rather than being presented as an isolated unit. One preview was morphologically related to the target, in that it included the target word's root morpheme within an alternative word pattern. This provided a preview benefit relative to an orthographic control, which shared the same number of letters with the target but was derived from a different root. Participants had clearly extracted the root morpheme in the parafovea, and used this to guide lexical access.

Deutsch et al. (2005) also investigated whether the morphological code of the word pattern is integrated across fixations. This was examined for both verbal patterns (i.e. word patterns that combine with the root to form a verb) and nominal patterns (i.e. word patterns that combine with the root to form a noun). An important difference between these two types of word patterns is that while the verbal patterns possess properties that may guide lexical access, the nominal patterns do not. Specifically, nominal patterns do not have precise semantic characteristics, and the frequency of most nominal patterns is low in comparison to the frequency of the verbal patterns. Deutsch et al. showed that it is possible to gain a morphological preview benefit from a preview consisting of the word-pattern in an alternative word in the case of verbs, but not nouns.

In summary, Hebrew readers decompose words into their constituent morphemes in the parafovea, and then integrate this information (usually) on the following fixation on the word in order to aid lexical identification. There is clearly a difference between parafoveal morphological processing for readers of Hebrew and readers of English and Finnish. The cross-linguistic difference that may most plausibly account for this is the speed with which it is possible to extract individual morphemes in the parafovea. In Hebrew there are strict rules governing which letters within a word can belong to each morpheme. This is not the case in English, with there being relatively few constraints upon where one morpheme ends and another begins. Indeed, the existence of the monomorphemic control words used in the English studies demonstrates this, with it being possible for *re* to either be a prefix or two letters in a monomorphemic word. Thus, readers of Hebrew have stronger cues with which to reliably morphologically decompose words than readers of English, and these cues may partially account for differences in the parafoveal extraction of morphological units.

Semantic information

Over the past several decades the predominant view has been that semantic information is not integrated across fixations, due to early findings from studies conducted primarily in English. Rayner, Balota, and Pollatsek (1986) presented participants with previews of a target word (e.g. *father*) that were semantically related (e.g. *mother*), orthographically similar (e.g. *fatlon*) or unrelated (e.g. *circle*). The semantically related previews provided no benefit, suggesting that semantic information was not carried over to subsequent fixations (see Rayner, Schotter, & Drieghe, 2014 for a replication). A similar pattern of results was found in a gaze-contingent naming study (Rayner et al., 1980). Further evidence against semantic information being integrated across fixations was found by Altarriba, Kambe, Pollatsek, and Rayner (2001). In this study, Spanish-English bilinguals read sentences with previews that were translations of a target word which were either orthographically similar (e.g. *crema* as a preview for *cream*) or dissimilar to the target (e.g. *fuerte* as a preview of *strong*), orthographically similar words in the opposite language that were not translations (e.g. *grasa* as a preview for *grass*), or an unrelated word in the opposite language (e.g. *torre* as a preview for *cream*). Since the translation shared a semantic representation with the target word, it was hypothesized that significantly more preview benefit might occur for the translation preview than the orthographically similar non-translation if semantic information was integrated across fixations. However, the amount of preview benefit was primarily driven by orthography, and not semantics. This study offers little support for the view that semantic information is integrated across fixations.

Research conducted on semantic preview benefit in Finnish also suggests that this information is not integrated across fixations. Hyönä and Häikiö (2005) gave participants parafoveal previews that were either correct (e.g. *pentu* ‘cub’), emotionally arousing (e.g. *penis*), or neutral (e.g. *penni*, ‘penny’). They hypothesized that if readers extracted semantic information from these previews then there would be disruption to reading in the emotional

condition, due to the possibility that this information would be arousing enough to disrupt processing. However, there was no effect of the emotive content of the preview.

Although these studies suggest that semantic information is not integrated across fixations, recent evidence suggests that this is not necessarily the case. Reliable semantic preview effects have now been observed in several studies of Chinese reading. In Chinese the majority of characters include a semantic radical, and therefore, there is a more direct link between the orthography and semantics of a word than in alphabetic languages. This makes it more likely that semantic information can be extracted in the parafovea, and then integrated on the next fixation. Yan, Zhou, Shu, and Kliegl (2012) examined whether semantic information from both the radical and character level is integrated across fixations. Participants were given an unrelated preview, and two different types of semantically related previews. One of the semantically related previews was semantically transparent, in that the meaning of the character was congruent with the meaning of the semantic radical, whereas the other was opaque. None of the previews contained the same semantic radical as the target character, and so any preview benefit could not be due to orthographic confounds. Yan et al. found that both types of semantic preview led to shorter reading times than an unrelated preview, with the semantically transparent preview leading to a larger benefit in gaze duration than the semantically opaque preview. This pattern of results demonstrates that semantic information from both the whole character and the radical is activated in the parafovea, and that both types of semantic information are then integrated with semantic information extracted from the target character upon fixation. This can be seen from the fact that semantic overlap between the preview and target character reduced target fixation durations, and that there was a greater effect when the preview's semantic radical and the target character also shared semantic information. Furthermore, Yan et al. observed larger

semantic preview effects when fixation times on the pre-boundary word were longer (see Hohenstein & Kliegl, 2014 for a discussion of this effect).

Semantic preview effects have also been observed in German. Hohenstein, Laubrock, and Kliegl (2010) found effects in German using parafoveal fast priming. In this technique, a nonword preview of the target word is present until readers make a saccade over an invisible boundary prior to the pre-target word. As a saccade is made onto the pre-target word, a display change is triggered. In the Hohenstein, et al. (2010) experiment, this led the target word to change to either a semantically related or an orthographically matched preview for a set amount of time before becoming the target. The amount of time the parafoveal preview was available for was varied. At short prime durations (e.g. 35, 60, and 80 ms) there was no semantic preview benefit. At a longer prime duration (125 ms) there was a significant semantic preview benefit of 24 ms. Furthermore, there was a change in this pattern of effects when the target word was made more salient via being presented in bold. Here a significant semantic preview benefit of 18 ms was found at the 80 ms prime duration, but no facilitation was found for the 125 ms prime. The authors claimed that this was due to semantic information being facilitative only up to a certain moment, beyond which the orthographic mismatch overrides the effect. Some caution may be necessary in interpreting these results as it is not entirely clear how the visual changes that occur in the fast priming technique influence attentional allocation during reading.

Hohenstein and Kliegl (2014) found further evidence for semantic preview benefit in German using the standard boundary paradigm. They found that a semantically related preview (e.g. *Schädel* ‘skulls’ as a preview for *Knochen* ‘bones’) was more facilitative than an unrelated preview that shared the same amount of orthographic information with the target word (e.g. *Stiefel* ‘boots’). This effect was reliable across fixation time measures over three experiments and averaged 26 ms in gaze duration. Furthermore, the effect endured regardless

of whether the target noun was capitalized or not (in German, nouns are capitalized). This is important since it may be easier to extract parafoveal semantic information for nouns in German since the capitalization may give readers a salient cue to the syntactic class of the parafoveal word, allowing for more processing resources to be allocated to that word than might otherwise be the case. Furthermore, there was an effect of pre-target fixation duration that was similar to that reported by Yan et al. (2012), such that there was a greater semantic preview benefit following longer fixations on the pre-target word.

The final study we will consider in this section is that of Schotter (2013). In this study investigating reading of American English, participants were given two different types of semantically related previews. The first type (e.g. *rollers* as a preview for *curlers*) was highly related to the target (7.5 on a 9 point rating scale in a norming study) and maintained the sentence meaning (7.2 on a 9 point rating scale). The second type (e.g. *styling*) was less semantically related (5.6) and maintained the sentence meaning to a lesser extent (4.9). Unrelated previews (e.g. *suffice*; 2.4 and 1.9 on the rating scales) were also included. All three previews shared a similar amount of orthographic information with the target. Relative to unrelated previews the highly related previews led to shorter fixation durations on the target word (16 and 19ms in gaze durations across two experiments). There was no benefit from less semantically related previews. Furthermore, the extent to which the preview changed the meaning of the sentence predicted fixation times on the target word. Schotter argued that this suggests the lack of effects in English in prior studies arose because the semantic relationship between the preview and the target word did not preserve meaning to the same degree that her stimuli did. For example, Rayner et al. (1986) used target-preview pairs such as *father-mother*, *ocean-river*, and *sick-well*, which while semantically related to each other, did not necessarily share the same meaning.

In sum, the evidence regarding whether semantic information is integrated across fixations is currently mixed. Some studies have failed to show clear effects, while other studies do appear to show effects often under specific experimental circumstances. It is not possible at present to provide a coherent explanation of the current state of this aspect of processing – in some senses it is quite contradictory. Further research is necessary in order to gain a clearer understanding.

THE INTEGRATION OF INFORMATION FROM WORD $N+2$

The preceding sections have all focused on how various types of information about the upcoming word ($n+1$) are integrated across fixations. Recently, however, research has begun to investigate whether information from word $n+2$ is also integrated across fixations (Angele & Rayner, 2011; Angele, Slattery, Yang, Kliegl, & Rayner, 2008; Kliegl, Risse, & Laubrock, 2007; Rayner, Juhasz, & Brown, 2007; Risse & Kliegl, 2012).

To investigate the integration of information from word $n+2$ across fixations, researchers have manipulated the preview of a word while it is two words to the right of fixation, with the preview changing to the target as a saccade is made onto the pre-target word (word $n+1$). Any effect of this manipulation would suggest that readers are extracting information from word $n+2$ when it is in the parafovea, and integrating this information during subsequent fixations. Rayner et al. (2007) presented participants with either a correct or incorrect preview of a target word, and manipulated whether the boundary was directly before the target word, or directly before the pre-target word. As such, the incorrect preview was either visible as word $n+1$ or word $n+2$. The preview manipulation only had an effect when the preview was visible as word $n+1$. Thus, Rayner et al. did not observe evidence for the integration of information from word $n+2$. Kliegl et al. (2007) further investigated this issue. In their study, word $n+1$ was always three letters long, thus ensuring that the preview of word $n+2$ was as close to central vision as was reasonably possible. Furthermore, they

tested for effects of the $n+2$ preview on fixation times on both word $n+1$ and $n+2$. While the $n+2$ preview did not affect fixations on word $n+2$, it did affect fixations on word $n+1$, suggesting that information from word $n+2$ was extracted (see Risse & Kliegl, 2012, for a discussion and test of why this effect appeared on word $n+1$). Angele et al. (2008) orthogonally manipulated previews of word $n+1$ and $n+2$ and ensured that word $n+1$ was always at least four characters long. They found that while there were reliable $n+1$ preview effects, there were no effects of the $n+2$ preview. The posited reason for the discrepancies across studies is the length and processing difficulty of word $n+1$. When word $n+1$ exceeds three characters it is more difficult to process, and therefore word $n+2$ is less likely to be processed before a saccade is made across the boundary. Furthermore, even when word $n+2$ is processed, information extraction occurs less efficiently, since it is further into the parafovea.

Angele and Rayner (2011) manipulated whether readers received identity or nonword previews of a three letter word $n+1$, and a word $n+2$ which was on average seven letters long. While $n+2$ preview effects were found when there was an identity preview of word $n+1$, there was no effect when it was a nonword. Thus, when word $n+1$ cannot be lexically processed (due to it being a nonword) information from word $n+2$ does not appear to be integrated.

More recently Cutter, Drieghe, and Liversedge (2014) found an $n+2$ preview effect even when word $n+1$ was long. In this study, word $n+1$ (e.g., *teddy*) was on average 5.65 letters long, and formed a spaced compound (e.g. *teddy bear*) with word $n+2$ (e.g. *bear*). Participants were given either a correct preview of both constituents, of only the first constituent, of only the second constituent, or of neither constituent. When the first constituent was correct, participants gained a sizeable $n+2$ preview benefit, such that gaze durations on word $n+1$ were 27 ms shorter when there was a useful preview of both constituents, rather than just the first. This demonstrates that while $n+2$ preview effects are

not typically observed given a long word $n+1$, this can be modulated by the extent to which word $n+2$ forms a single multi-word unit with word $n+1$. Furthermore, it shows that the absence of $n+2$ preview effects in prior studies was not due to visual limitations.

In summary, there is evidence for information from word $n+2$ being extracted, and arguably, integrated across fixations in English, but only under specific circumstances. The studies reviewed suggest that word $n+1$ must be short and easy to process for information from word $n+2$ to be extracted and integrated across fixations. Furthermore, even when such effects are observed they are small (e.g. 7 to 20ms) when compared to effects of word $n+1$ (e.g. 20 to 50 ms). The one exception to this is when word $n+2$ was part of a spaced compound, an issue that we will return to below.

MODULATING FACTORS

So far, we have discussed the extent to which information is integrated across fixations as if this is an invariant process. However, several factors have been shown to modulate this process. The first is foveal load, and the second is the extent to which the foveal and parafoveal word can be considered a single unit.

Foveal load refers to the difficulty of processing on any particular fixation. When the currently fixated word is difficult to process, then foveal load is high. It has been argued that increased foveal processing load results in reduced parafoveal processing (Henderson & Ferreira, 1990; White, Rayner, and Liversedge, 2005), thus reducing the extent to which information may be integrated across saccades. Henderson and Ferreira manipulated foveal load via either a word frequency or a syntactic manipulation and presented participants with a correct or incorrect preview using the boundary paradigm. Significant effects of the preview type were only observed when the foveal load was low. The effect of the foveal word's frequency on preview benefit has also been observed by White et al. (2005).

While several studies have shown that foveal load modulates the parafoveal preview benefit, research by Drieghe, Rayner, and Pollatsek (2005) suggests that this is not always the case. In this study, foveal load was varied using the same frequency manipulation as in earlier studies, and participants were given a preview of a three-letter target word. However, the size of the preview benefit was the same for the high and low foveal load conditions. Drieghe et al. proposed that the absence of an interaction may have been due to the short parafoveal words being processed differently from the longer parafoveal words used in other investigations of foveal load. However, it is unclear why the length of a parafoveal word would determine the extent to which foveal load influences parafoveal processing. More work is required to further explore this effect.

A second factor that influences how far into the parafovea information is extracted from and then integrated across fixations is the degree to which the foveal and parafoveal text is unified spatially and linguistically. This is an issue that has been touched upon throughout the current chapter. In terms of spatial unification, a larger preview benefit is observed when the preview is of the end of the fixated word (e.g., 151 ms in gaze durations on the second half of a word in Drieghe et al., 2010) than when the preview is of the word to the right of fixation (e.g. an average of 41 ms for dissimilar letters in Hyönä et al., 2004). Even less of an effect is observed from previews of word $n+2$, with the literature only finding effects of between 7 and 20 ms. The one exception to this was Cutter et al.'s (2014) study, in which a 27 ms effect was observed in gaze duration on word $n+1$ when word $n+2$ formed a spaced compound with word $n+1$. This effect suggests that whether two physically separated parafoveal words form a single lexical unit or not influences the amount of information integrated across fixations.

The results of several studies suggest that the lexical unification of information within a fixated word also influences the extent and time course of the integration of information

from the end of this word. As discussed in the section on within-word integration, it has been found that people differentially integrate information from the end of unspaced compounds and monomorphemic words (Drieghe et al., 2010). Furthermore, Häikiö et al.'s (2010) study suggested that information from the end of unspaced compounds was integrated differently depending upon whether the compound was identified as a single lexical unit or two separate lexemes. Häikiö et al. showed that when an unspaced compound was identified as a single lexical unit, incorrect information at the end of the second constituent was integrated early enough to affect fixations on the first constituent. This was not the case when the unspaced compounds were processed as two separate lexemes. Thus, this research suggests that the time course in which information is integrated across fixations is modulated by whether the information in the fovea and parafovea are processed as part of the same lexical unit.

There is also evidence that a greater amount of information is integrated from word $n+1$ when it forms part of a larger unit with the fixated word (Inhoff, Starr, & Shindler, 2000; Juhasz, Pollatsek, Hyönä, Drieghe, & Rayner, 2009). Inhoff et al. examined preview benefit for the second word of spaced compounds (e.g. traffic light, fairy tale, video tape). This study found a considerably larger preview benefit than is usual between words, such that there was a 91 ms effect of a dissimilar preview in comparison to the average of 41 ms (Hyönä et al., 2004). Furthermore, the manipulation affected fixation times on the first constituent, in a similar manner to preview manipulations within monomorphemic words (Drieghe et al., 2010) and frequent unspaced compounds (Häikiö et al., 2010). Juhasz et al. also found a larger than usual preview benefit for the second constituents of spaced compounds (34 ms vs. an average of -7 ms for studies using an equivalent level of disruption), although this study did fail to find significant differences between spaced compounds and adjective-noun pairs, for which there was a 21 ms effect. The findings of both Inhoff et al. and Juhasz et al. suggest that a greater amount of information may be extracted from a parafoveal word if it forms part of a

larger unit with the foveal word. Furthermore, Inhoff et al.'s finding indicated that this parafoveal information may have been integrated earlier than is typical for a parafoveal word that does not form a single unit with the fixated word.

To summarize, several factors have been found to influence the extent to which parafoveal information is integrated across fixations. One is foveal load, with preview benefit effects being reduced when the fixated word is difficult to process. The second factor is the extent to which the information in the parafovea forms a single unit with the fixated word.

CONCLUSION

We have seen that a large variety of information is integrated across fixations, from both the end of a single word and from a parafoveal word. The integration of information from word $n+1$ operates on the basis of abstract codes for word characteristics such as orthography, phonology, semantics, and, in the case of Hebrew, morphology. There are several interesting cross-linguistic differences that influence the information which is preferentially integrated across fixations. For example, readers of English preferentially integrate word-initial letters, Chinese readers integrate the final radical of the parafoveal character, and Hebrew readers integrate morphological codes. The underlying reason for these differences may well be the extent to which the information allows the reader to initiate lexical access. For readers of English, the phonological code granted by the word initial letters may be most useful, while in Hebrew the root morpheme may provide more useful information for activating appropriate lexical candidates. Finally, in Chinese the final radical may provide more discriminative information to activate a limited set of character candidates. As such, research suggests that information is integrated across fixations on the basis of the most useful information for identifying words in a particular language. While the research shows that a large amount of information about word $n+1$ is integrated across fixations, the same is not true for word $n+2$, with preview manipulations to this word having small effects

that only occur under optimal conditions. Finally, the way in which readers integrate information across fixations is influenced both by foveal load and whether the parafoveal text forms a larger unit with either the foveal text or more distal parafoveal text.

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